AC 2007-2488: DEVELOPMENT OF A TEACHER EDUCATION CURRICULUM BASED ON ENGINEERING PRINCIPLES AND CONCEPTS

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Introduction

The rate of technological innovation has become such that it has become almost impossible for any individual to keep abreast of all the current and upcoming developments. The oft-quoted statement from Arthur C. Clarke,

Any sufficiently advanced technology is indistinguishable from magic.[1]

is for all intents and purposes the reality for many individuals. As engineers, it is one thing to shake our heads when someone claims that they have no idea how a light bulb or an internal combustion engine works, but can we really be surprised when someone expresses a sense of wonder when they learn that a tiny unpowered USB device can store 4 GB of data?

Ten years ago, engineering programs were beginning to introduce the concept of 3-D modeling to students who had problems using a mouse to zoom, pan and rotate a solid model. Yet today, grade-school children play video games that exist in fully 3-D virtual worlds and they can build their own solid models using kid-centric programs such as *Lego Digital Designer*.[2] During the same period of time:

- The Internet has gone from the research tool and the "next new thing" for technophiles to being an almost defacto necessity for conducting our daily lives.
- The cell phone has gone from the defining aspect of being a "Yuppie" to being a part of the standard walking around items for a huge percentage of the global population. As of 2006, 80% of world's population has mobile phone coverage.[3]
- Television screens have become bigger while the sets have become thin, film cameras have been replaced by the CCD, GPS navigation has become a standard option on most cars, CD's have been replaced by MP3's, which have been replaced by iTunes, and China has become the factory for the world.

As educators, we need to ask ourselves, "At what point does the rate of growth of technology begin to outpace the population's ability to keep pace with it?" The second question that needs to be asked is, "What mechanism have we built into our education system that prepares our future citizens to be an informed populace?"

Many studies have been conducted, reports written, and papers published that have considered these question and some means by which they can be addressed.[4, 5, 6, 7, 8, 9] One of the primary conclusions that can be gleaned from these works is that our national education system needs to produce students who are creative problem solvers.

In a recent interview, an engineering manager from Lockheed Martin Space Systems involved in the system testing for the Phoenix Mars Mission[10] (Launch: August 2007) made the following observation:

The most important quality for an engineer is the ability to be creative in their solutions to problems. The math, science, and engineering concepts that they are taught are important foundations, but modern engineering practice uses many computer-aided design tools that solve the structural, fluid, and thermal calculations. The good engineer is one who can use these tools as a part of the creative design and/or problem solving process.[11]

Obviously, some aspects of the present educational philosophy and its emphasis on "teaching to the test" are in direct conflict with the development of the ability to creatively solve problems. Of course, another aspect of this same topic is that a good problem solver also has to have the ability to recognize the problem. As an example of this second point, consider the following statement:

Water freezes at 0 degrees Celsius and 32 degrees Fahrenheit. Water boils at 100 degrees Celsius and 212 degrees Fahrenheit. Determine the relationship between the Celsius scale and the Fahrenheit scale.

This can be equivalently stated as:

Determine the equation of the straight line that passes through points (0, 100) and (32, 212).

I have assigned the first stated task to many people over the years, and it is surprising how few of them recognize that the solution requires the application of algebra. It is understandable that individuals may be a little rusty on the methodology for calculating the equation of a line through two points, but it is disturbing that so many people don't recognize the problem at all. This is in essence the point being made about what makes a good engineer – an engineer needs to be able to recognize the problem in order to solve the problem.

So we are faced with two equally daunting problems for our educational system:

1. How do we produce students who are technologically literate and have the ability to stay technologically literate in an ever-changing world.
2. How do we produce students who are adept both at recognizing problems and at solving them in a creative manner.

Solving the Problem

It is clear that the solution to the two questions posed above requires a rethinking of our nation's educational objectives. One large aspect of the solution is the process of integrating aspects of science, technology, engineering, and mathematics into the educational framework. This STEM educational philosophy recognizes that these four subject areas should be considered as a whole and not as separate entities. One major problem with the STEM concept is that conventional K-12 curriculums typically only cover the science and mathematics subjects with what may be considered national uniformity. The other two facets of STEM, technology and engineering, are relegated to the "technology departments" within the middle schools and high schools and despite efforts by the International Technology Educators Association (ITEA) there does not yet exist a national model for these programs. The Standards for Technological Literacy[4] provides guidelines for technology education; however, the preface to these standards states:

> *Standards for Technological Literacy presents a vision of what students should know and be able to do in order to be technologically literate. These standards do not attempt to define a curriculum for the study of technology; that is something best left to states and provinces, school districts and teachers.*

Thus, at the present time there does not exist a single national model for the curriculum that should be used to teach technology. As a result, the technology programs from state to state, and from district to district within individual states, vary widely in both quality and content, with no defined metrics to test student aptitude. Thus one school's technology program may provide students with instruction in cabinet making and metal working while another school in the next school district may be teaching digital electronics, robotics and, multimedia design.

The goal of any far-reaching STEM program needs to address the curriculum needs of technology education. Programs such as Project Lead the Way (PLTW)[12] and The Infinity Project[13] have stepped into this perceived curriculum void and have created programs that bring structure and metrics to some aspects of technology education. In fact, one of the implementation actions put forth in the report *Rising Above the Gathering Storm*[6] is to produce K-12 curriculum materials modeled on a world-class standard, and it states that a model for this action is the Project Lead the Way pre-engineering courseware.

While programs such as PLTW and The Infinity Project have many things to offer to students, they are not for all students. One of the primary goals of the PLTW program is to "Increase the number of young people who pursue engineering and engineering technology programs requiring a four- or two-year college degree."[14] Thus while a program like PLTW has offered some structure to technology education it leans heavily toward the engineering component of STEM. This still leaves the general technology aspect of STEM without a defined curriculum.

The disparate nature of technology education programs is both a legacy of their past incarnation as "shop classes" and the lack of any formal curriculum that can be coupled with the *Standards for Technological Literacy*. However, almost all technology education programs have the following things in common:

- They provide students a mechanism through which they can learn about the designed world – architecture, energy, transportation, communication, etc.
- The process of design is emphasized and somewhat formalized via the introduction of the concept of the design loop.
- The design loop/process is typically used to create tangible objects. For many students this is their only experience at being creative in a formalized setting with specific requirements for outcomes.

- Students are encouraged (required) to be active participants in the learning process. Students “learn by doing” as they explore the process of problem solving.

The ideal technology education program would be all these things and incorporate science and math concepts into all aspects of the creative/problem solving/design processes.

Thus the best technology education programs incorporate STEM methodology and:
- address the need that all students understand the basic operation of the technological world that surrounds them.
- provide the opportunity for students to develop and apply problem-solving skills to problems that have no unique solution.
- emphasize the importance of team work.
- emphasize creativity.
- emphasize hands-on skills by allowing students to create tangible objects.
- challenge and instruct the students to synthesize their previous learning in order to formulate problem solutions. This obviously includes the “appropriate” math and science.
- challenge students to move outside their comfort zones (except – of course – in the case of the use of such items as power tools).
- continuously modify their programs to reflect the changes in the technological world.
- emphasize communication skills, both verbal and written, and teach the concept of documentation.
- encourage students to participate in team-centered problem-solving programs. Examples of some of the many programs that technology education programs can incorporate into their programs are the FIRST Robotics programs[15], the Botball robotics program[16], the Junior Engineering Technical Society (JETS),[17] and the Technology Student Association (TSA).[18]

Revision of a Curriculum

The implementation and maintenance of a national top-flight technology education program require a steady supply of specialized technology teachers. The emphasis on STEM education, the ever-increasing pace of technological innovation, and the specialized requirements of programs such as the Infinity Project and PLTW have required a change in the basic education of a technology education professional.

In an effort to begin to address these challenges the Department of Technological Studies of The College of New Jersey has begun to reshape both the make-up of its faculty and the focus of its curriculum. During the past year, two senior members have retired and the department has hired two new faculty to fill these openings. The retiring faculty both held doctorates in education with a focus on industrial arts – one of the new faculty members has a doctorate in aerospace engineering and the other has a doctorate in electrical engineering. These two new faculty members are helping to accelerate the department’s move away from a more traditional design-based technology education/industrial arts program toward a more rigorous STEM-based program that emphasizes design models based on mechanical and electrical engineering concepts.

The goal of our program is to produce graduates who have all the abilities and knowledge that will make them a valuable resource to a top-flight technology education program. In order to accomplish this our program has determined that it needs to:

- Recruit students with an interest in technology. It is important to note that these students are not engineering students. A majority of the students come out of successful and vibrant technology education programs. Most of these students have adequate math and science skills but their perceived strengths lie in the realm of hands-on learning, team work, and problem solving.
- Stay abreast of the technology that is available in the schools and provide instruction in its use and pedagogy.
- Develop an instruction methodology that students can use to develop and hone their own problem-solving skills.
- Include instruction in both Calculus and Physics
- Provide a mechanism by which our students can increase their understanding of the critical intersection of math, science, and technology/engineering and develop a pedagogy to build this understanding into their teaching process.
- Develop a comprehensive understanding of the various design-world professions (e.g., engineer, architect, media production specialist) and how their specialized areas of expertise are combined by successful businesses to create innovative products such as the Apple iPod and the Toyota Prius.

A Tech Ed teacher preparation program must strike a careful balance between addressing the current needs of the community which it serves (the current tech ed programs – who hire the teachers) and the future needs of these programs. Thus the program curriculum needs to be forward-thinking in its curriculum development but not so much so that it prepares students for jobs that don't exist.

In 2004 the department began a process of curriculum review. In order to gain an outside perspective, an advisory board made up of individuals from industry, engineering programs, and K-12 technology educators was formed. The advisory board included the following individuals: Michael Andrusiewicz, Technology Teacher (M.E.), South Brunswick High School, NJ; Celeste Baine, Director, Engineering Education Service Center, Eugene, OR; Paul Bracciante, Assistant Principal, Williamstown High School, NJ (a PLTW school); Robert Dorn, Director of Northeastern & Mid-Atlantic States, Project Lead the Way; David Gattie, Assistant Professor, Department of Biological & Agricultural Engineering, Faculty of Engineering, University of Georgia, Athens, GA; Michael Klavon, Director of Office of Innovative Programs & Schools, New Jersey Department of Education, Trenton, NJ; Anne O'Neill, IEEE SSCS Executive Director, Piscataway, NJ.

This board was asked to provide insight and feedback on the following questions:

- What are appropriate engineering principles for 9-12 education?

- What should teachers know and be able to do in order to teach pre-engineering principles?

In addition to providing feedback on these questions, the Advisory Board also provided valuable information about pre-engineering initiatives throughout the United States.

During the 2005-06 and 2006-07 academic years, the department has developed and begun to implement a revised curriculum that addresses many of the advisory board's recommendations – the full four-year sequence is provided on the following page. The curriculum has three major components: Liberal Learning, Education courses, and three technology threads – mechanical systems, electrical systems, and the designed world.

The major revisions have been:

- A substantial increase in the basic math and science requirements in the Liberal Learning program that now requires the students to take
    - Calculus A
    - Engineering Math
    - General Physics I
    - Choice of Physics II, Biology I, Chemistry I, Computer Science I
- The implementation of three complimentary technology threads.
    - Mechanical Systems
        - Structures and Mechanics
        - Mechanisms and Materials Lab
        - Thermo/Fluid Systems
        - Mechanical Systems Design
    - Electrical Systems
        - Analog Circuits and Devices
        - Digital Electronics
        - Instrumentation and Controls Lab
        - Mechatronics
    - Designed World
        - Creative Design
        - Engineering Design
        - Multimedia Design
        - Architectural and Civil Engineering Design
        - Prototyping Laboratory
        - Manufacturing Systems

The complete four-year course of study is outlined on the following page. The revised curriculum as presented here is still in its formative stage and its content needs to be refined and implemented over the course of the next four years, beginning with the Fall 2007 incoming freshman class.

Department of Technological Studies – The College of New Jersey

Technology Education/Pre-Engineering Teacher Certification Program
Four-Year Sequence

Freshman I (4 Units)

FSP ____/First Seminar Program
MAT 127/Calculus A
ETE 261/Multimedia Design
TST 161/Creative Design

Freshman II (4 Units)

PHY 201/General Physics I
ETE 111/Engineering Design
ETE 131/Engineering Math
____ ____/Liberal Learning Elective
____ ____/Academic Writing (0.0 Units)

Sophomore I (4.5 Units)

____ ____/General Science Elective**
ETE 271/Structures and Mechanics
ETE 275/Mechanics and Materials Laboratory*
TED 280/Introduction to Teaching Technology
____ ____/Liberal Learning Elective

Sophomore II (4 Units)

ETE 281/Analog Circuit and Devices
ETE 279/Thermo and Fluid Systems
ETE 361/Architectural and Civil Eng. Design
SPE 203/Psychological Dev. Child/Adolescent

Junior I (4 Units)

ETE 283/Digital Electronics
ETE 365/Prototyping Laboratory*
ETE 371/Mechanical Systems Design
SPE 323/Literacy and Inclusion*
____ ____/Liberal Learning Elective

Junior II (3.5 Units)

TED 380/Junior Professional Experience
ETE 285/Instrumentation and Controls Lab.*
ETE 381/Mechatronics
TED 360/Integrated M/S/T for Young Learners

Senior I (4 Units)

TED 480/Content and Methods
ETE 481/Seminar
ETE 490/Student Teaching (2 Units)

Senior II (4 Units)

ETE 495/Senior Design Project
ETE 461/Manufacturing Systems
TED 492/Facilities Design and Management
____ ____/Liberal Learning Elective

* 0.5 unit courses

** Approved List: Phys 202/General Physics II, Bio 185/Themes in Biology, CHE 201/General Chemistry I, CSC 215/Computer Science I for Science and Engineering

While it is not practical to present the content of all the courses contained in this four-year sequence within the scope of this paper, the first course in the mechanical engineering design sequence will be briefly described to provide an example of the program goals. It should be noted that the course description represents a synthesis of lessons learned during the past two years. The course as described below will be introduce during the Fall 2007 semester. More complete information on this and other courses within the program sequence can be accessed at the Department of Technological Studies Web site (http://www.tcnj.edu/~tstudies/).

ETE 271/Structures and Mechanics

Course Objective: Provide students with a basic understanding of the fundamental tools used to analyze and describe simple mechanical structures and mechanisms. The course revisits many of the basic concepts introduced in General Physics I with a goal of reinforcing the student's understanding of concepts of Newton's laws of motion and the conservation laws for energy and momentum. The course also introduces the students to the concept of the design process and provides instruction in technical documentation.

Course Structure: The class meets three times a week – there are two lecture/lab periods that meet for two hours and a design period that meets for one hour. During the lecture/lab periods course material is introduced through short lectures that are augmented by hands-on projects, experiments, and demonstrations that are designed to illuminate and reinforce the physical laws and concepts. The one-hour design period is used to provide introduction to various technologies (Fischertechnik, Lego, Knex, Vex) and building techniques (balsa wood and foam core models) that are used in the typical technology/pre-engineering classroom.

Course topics include:

- Newton's Laws, projectile motion, conservation of energy and momentum
- Free body diagrams
- Static equilibrium (solution of 2-D systems)
- Simple truss structures
- Concepts of stress, strain, elasticity, and elastic limit
- Simple machines and mechanical advantage
- Gears and the relationship between speed and torque
- Pulley systems
- Basic mechanisms (clock escapements, simple toys)

Future Plans

As has been stated, our goal is to produce a new type of teacher who has the ability to teach a rigorous hands-on technology program that encompasses the fundamental concepts of the engineering profession. When the findings of the report *Rising Above the Gathering Storm* were presented to the 109th United States Congress on 20 Oct. 2005, one of the key points was that two-thirds of U.S. high school students are taught science by teachers with no major or certificate in chemistry or physics. The numbers are even worse for technology education. In fact, many of the Project Lead the Way classes are taught by technology teachers who, besides the two-week preparation course required by PLTW, have no formal background in engineering.

Our continuing goals for our program are:

- Maintain a high-level of hands-on learning within all courses. One of our department's driving tenets is that ***teachers will teach as they are taught***. Our department has been very successful at producing top-flight teachers who are able to engage their students. Thus it is critical that the new curriculum maintain this fundamental instructional aspect.
- Create a seamless flow of learning between the various classes. The overall goal is to achieve an integrated curriculum. A possible model is the "fully integrated second-year mechanical engineering curriculum" that has been developed by the University of British Columbia.[19]
- Incorporate design tools that allow for creativity and problem-solving independent of machine and wood shop limitations, such as Lego Mindstorms, the Vex robotics design system, and Fischertechnik modeling system. The goal is to utilize these systems throughout all the courses within the curriculum. As the students gain sophistication with these tools they will be better able to focus their energies on the solution of design problems.
- Continue the use of such tools as the Parallax Basic Stamp microcontroller and the A-Wit Technologies C-Stamp in the instruction of electrical engineering principles. As with the modeling systems, our goal is to allow our students gain a sophisticated knowledge of these tools by incorporating their use at many points throughout the curriculum.
- As future in-service teachers, our students will become responsible for the mentoring of students as they participate in programs such as the FIRST Lego League, FIRST Vex Challenge, FIRST Robotics Competition, Botball Robotics, etc. Thus we would like to incorporate the mentoring of actual student teams into our program. Our department is currently working with one local high school and we hope to expand this program into both the local middle schools and primary schools.
- Our department is also interested in performing a preliminary study on the redesign of our teaching/lab areas. As we move toward the development of this innovative curriculum, we will need to evaluate the type of work environment that is best suited to the instructional philosophy. Items that need to be considered in the "teach as they are taught" philosophy will be: access to design materials, well-designed workstations that allow for group work, and the appropriate use of such instructional tools as interactive whiteboards, etc.

Notes

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[1] Clarke, A. C., Profiles of the Future, 1962

[2] http://ldd.lego.com/

[3] http://en.wikipedia.org/wiki/Mobile_phones/

[4] *Standards for Technological Literacy: Content for the Study of Technology*, 2nd edition, International Technology Education Association and its Technology for All Americans Project, 2000.

[5] *Technological Literacy for All: A Rationale and Structure for the Study of Technology*, International Technology Education Association, 2005.

[6] *Rising Above the Gathering Storm – Energizing and Employing America for a Brighter Economic Future*, Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology, Committee on Science, Engineering and Public Policy, National Academy of Sciences, 2006.

[7] Salinger, G. L., "The Engineering of Technology Education," The Journal of Technology Studies, Volume XXXI, Number 1, Winter 2005.

[8] Hansen, J. W., "The Ingenuity Imperative," The Journal of Technology Studies, Volume XXXI, Number 1, Winter 2005.

[9] Loepp, F. L., "Standards: Mathematics and Science Compared to Technology Literacy," The Journal of Technology Studies, Volume XXX, Number 1, Winter 2004.

[10] http://phoenix.lpl.arizona.edu/

[11] Matthew Cox – Private Communication, Jan. 2007.

[12] http://www.pltw.org/index.html/

[13] http://www.infinity-project.org/index.html/

[14] http://www.pltw.org/about/mission-goals-core-values.html/

[15] http://www.usfirst.org/

[16] http://www.botball.org/

[17] http://www.jets.org/

[18] http://www.tsaweb.org/

[19] Ostafichuk, P., et al., "Mech 2: A Fully-Integrated Second-Year Mechanical Engineering Curriculum", 2005 ASME Curriculum Innovation Award Winner, http://www.asme.org/Education/College/Education_Awards.cfm.